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Temperature performance of different pervious pavements: Rainwater harvesting for energy recovery purposes.

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Abstract

Pervious pavements offer a solution for rainwater runoff treatment in urban areas, combining storm-water management with water reuse purposes when the sub-bases become rainwater reservoirs. Furthermore, the thermal behaviour research into these systems has demonstrated their contribution to palliating the urban heat island effect in the hottest season and to delaying freezing during the coldest season. Recent investigations related to pervious pavements and their sub-bases have enabled the use of these structures combined with Ground Source Heat Pumps (GSHP) in addition to the other well-known applications. The aim of this field study is to investigate the temperature response observations of the water stored in the sub-bases of different pervious pavements under specific conditions, in order to evaluate the possibility of introducing GSHP technology. The base and sub-base temperatures of different types of pervious pavements were monitored during one year and the results obtained show the

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differences in pervious pavements temperature compared to air temperature over the period of study; and demonstrate that the sub-base is less affected by the air temperature than the base, due to the insulating capacity of pervious pavements. On the other hand, water samples were taken from the different pervious pavement sub-bases in order to assess the water quality deterioration due to the temperatures reached in the sub-base, focused on investigating the presence of *Legionella* in this particular aquatic environment.

Keywords: Storm-water management, pervious pavement, Ground Source Heat pumps (GSHP), water quality.

1. Introduction

Best management practices (BMPs) and Sustainable Urban Drainage Systems (SUDS) are well-developed agricultural and urban runoff control instruments (Kaini *et al.*, 2012; Panagopoulos *et al.*, 2011; Pratt *et al.*, 1995). The use of SUDs to control urban rainwater quantity and quality aspects has been investigated during the last decades in countries such as the USA and some European nations (Day *et al.*, 1981; Field *et al.*, 1982; Raimbault *et al.*, 1985; Pratt *et al.*, 1989; Pratt *et al.*, 1995). Techniques have been developed to improve urban drainage in a sustainable way and their use has increased all over the world. Pervious pavements are an important subset of SUDS (Rodriguez *et al.*, 2005) which help in flow control, allowing rainwater infiltration and reducing urban runoff formation; which have become accepted as valuable tools for rainwater reuse and management.

Pervious pavements are used in various environmental applications and their efficiency has been proved in removing pollutants such as hydrocarbons (Pratt *et al.*, 1999; Newman *et al.*, 2002), metals (Legret and Colandini, 1999), nutrients (Brattebo and Booth, 2003) and suspended solids (Gilbert and Clausen, 2006). Pervious pavements are also capable of reducing the heat island effect by means of evaporative cooling since porous layers retain a significant amount of water, which is released back into the atmosphere through evaporation during sunlight hours (Vu Thanh and Takashi, 1997; Wanphen and Nagano, 2009).

Rainwater harvesting using permeable pavements has enhanced the SUDS techniques with energy applications before rainwater is reused by introducing ground source heat pumps (GSHPs) systems (Coupe *et al.*, 2009; Scholz and Grabowiecki, 2007). The GSHPs make use of low-temperature energy by increasing/decreasing the outgoing fluid temperature of the ground during the heating/cooling mode and are a well-recognised source of renewable energy (Sanner *et al.*, 2003). This technology operates by introducing heat exchangers with a heat transfer fluid inside at the bottom of the sub-base to recover and deposit the heat in a similar way to geothermal systems. Besides, investigations in the University of Edinburgh have shown the effect of temperature on water quality in such systems (Scholz and Grabowiecki, 2009) highlighting the influence on biological growth of pathogenic organisms. It is concluded that the effect of the heating and cooling mode in the simulated earth energy system did not influence the removal efficiencies of the permeable pavements under experimental conditions (Tota-Maharaj *et al.* 2010).

The temperature of subsoil at 0.5m below ground is strongly influenced by local climatic conditions; moreover, variation in sub-base water temperature due to rainfall and seasonal fluctuations would cause undesirable variations in efficiency. To develop these systems it is necessary to know the temperature response of pervious pavements throughout the year under local climatic conditions. Observations of the temperature in pervious concrete pavements have shown how surface temperatures are higher than the air temperature due to solar radiation absorption, while the insulating capacity of the air mass in the pervious pavement and aggregate base produces a temperature decrease which becomes more buffered as depth increases (Kevern *et al.*, 2009; Bäckström, 2000). Part of the solar radiation is employed in evaporating the water retained in the porous material, which explains the lower temperatures obtained in pervious pavement surfaces. However, pervious materials with large void size can drain more easily at deeper layers so less water is kept near the surface where it is available for evaporation so reducing the cooling effect. This implies that the pavement warms like an impervious pavement (Asaeda and Ca, 2000).

The main objective of this study is to evaluate and compare the temperature distribution throughout the sub-base, which is composed of aggregates and water for each experimental parking bay, under different pervious pavement surfaces and specific weather conditions. The study includes different typologies of pervious pavement and the presence and absence of a geotextile layer in the parking bay configuration. Moreover, with the aim to use the sub-base as a GSHP system, water analyses have been done paying special attention to *Legionella* detection. The presence of this bacteria in water stored in the sub-bases, as a human-made water environment, is relevant if this reservoir is to be employed for thermal energy applications with temperature increments that promote *Legionella* proliferation (Fields, 1996; Fields, Benson and Besser, 2002). During the cooling mode in the GSHP application, the water temperature is expected to be higher than the natural temperature obtained from the parking bay observations, due to the sub-bases act as heat sinks for the spaces they are intended to cool. For that reason the sub-base will be considered a thermally altered aquatic environment for energy applications.

2. Materials and methods

2.1. Study location

The University of Cantabria is involved in the design, construction and monitoring of an experimental pervious parking area in Northern Spain (Santander). Different types of pervious pavements have been constructed, in order to study their effect on water storage (Gomez-Ullate *et al.*, 2010). The experimental parking area has been monitored since 2008 and temperature sensors were installed during construction to evaluate the long-term temperature performance within the pavements.

The experimental parking area consists of 45 parking bays built with different types of pervious pavements: concrete block, porous asphalt, porous concrete, reinforced grass with concrete grid and reinforced grass with plastic grid (Fig. 1). Each parking bay is an individual waterproof unit of 4.2m long, 2.4m wide and 0.5m deep, apart from one conditioned parking bay for handicapped people of 4.2 x 4.8m of surface. Pervious pavements allow the water to

drain through the pavement and the base into the aggregate sub-base where the water is stored. There is a geotextile installed in most of the parking bays between the base and the sub-base in order to separate the material of both layers. The common structure is formed with the sub-base layer (0.35m of clean limestone with voids ranging from 33% to 35 %); the geotextile layer; the base layer (0.05-0.07m of clean limestone); and lastly, the surface layer.

In order to study their temperature performance under the local climatic conditions, 11 different parking bays are selected. The characteristics of the pervious pavement types thermally monitored in this study are shown in Table 1. Unfortunately, one of them (PA1) was missed due to technical problems with the temperature probes installation.

2.2. Data collection

The measurement instruments are 20 Pt100 temperature probes (accuracy $\pm 0.13^{\circ}\text{C}$ at 20°C) and 3 eight channel dataloggers (accuracy $\pm 0.1^{\circ}\text{C}$). The air temperature, wind velocity, precipitation and solar radiation data have been provided by the Spanish State Meteorological Agency (AEMET).

The location of the pervious pavements selected is shown in Fig. 2. The pervious pavement temperatures were registered with temperature probes immersed in the base and the sub-base of each parking bay. There are two tubes horizontally placed in order to introduce the temperature probes and protect them from the granular material. The temperature sensors were conducted by pairs to the perforated pipes at the corner of each parking bay through corrugated tubes placed inside the pervious pavement. One sensor is located at 0.15m depth, just above the geotextile, and the other sensor is situated at 0.50m depth, at the bottom of the sub-base; as shown in the scheme in Fig. 3. Temperature measurements and meteorological variables were taken every 30 minutes for one year. Pavement surface temperatures are not measured because the investigation is focused on the sub-base temperature behaviour during the period of study.

2.3. Sub-base water sample collection

Each parking bay in the experimental parking lot is connected to a control manhole through two pipes: the bottom pipe, at the bottom of the sub-base, and the emergency pipe, at the height of the geotextile, just over the sub-base reservoir layer. For the water quality analysis, 3 types of pervious pavement were selected among those present in the experimental parking lot: concrete block, porous asphalt and reinforced grass with concrete grid. Samples were taken from the bottom of the sub-base of 3 parking bays of each type, in order to get 3 replicates of the types under study.

In situ measurement of temperature, conductivity, pH and dissolved oxygen parameters were done during the water sample collection. Laboratory instruments were utilized for turbidity, total hardness, and low range tests for the standard methods of OGD, total phosphorus and total nitrogen determinations. The biological activity was determined by the MPN method for heterotrophic bacteria detection, whose concentration was estimated employing the general-purpose liquid culture media and the incubation time at 22°C and 36°C was seven days.

The isolation method of *Legionella Pneumophila* was done according to the ISO 11731:1998 standard. Water samples were collected in sterile plastic bottles on 5-June-2009, and stored at 4°C until analysis in the laboratory, which was carried out within 24h of collection. Volumes of 1000ml of water were filtered through Cellulose Nitrate Membranes and samples from the selected water sources were examined for *Legionella* using culture media (selective and non-selective). Presumptive *Legionella* colonies on BCYE agar were confirmed by their inability to grow in the absence of cysteine and iron. No further confirmatory tests were carried out.

3. Results and discussion

3.1. Temperature response

The pavement temperatures depend greatly on the weather, normally changing every hour and from day to day. However, some differences can be appreciated during the

measurement period. In order to clearly show the temperature response, two weeks periods of different months of the experimental year are represented. The three periods showed in the graphs correspond to the coldest, warmest and most rainy months respectively (Fig. 4, Fig. 5 and Fig. 6); and temperatures reached in both, base and sub-base, for the different typologies of pervious pavements, air temperature and precipitation can be compared. Strong temperature oscillations in the sensor measurements at 0.15m depth and less appreciable oscillations in the sensor measurements at 0.50m, corresponding to the sub-base, can be seen. As for the sub-base temperatures obtained, heat transfer through the pavement and base, and the insulating ability of the porous layers produce a buffered temperature response with increasing depth, as is shown in the graphs (Fig. 4, Fig. 5 and Fig. 6), where the daily temperatures of the pervious pavements at 0.50m depth present smaller fluctuations.

The larger differences are observed between the PC1_s and the PA2_s and PC2_s (Fig. 6), where the sub-base temperatures obtained are higher during the autumn months. This may have happened due to a failure of the equipment.

The temperature measurements were not normally distributed and the Wilcoxon signed-rank test was applied for pairwise comparison of temperature data obtained from sensor 1 and sensor 2; the statistical software program SPSS® version 18 was used for the statistical analysis. The analysis shows significant differences between each pair of related samples, which includes the temperature measurements at two depths for each parking bay so that the thermal response of the base at 0.15m depth (sensor 1) and sub-base at 0.50m (sensor 2) depth are significantly different ($p < 0.01$).

Clustering analyses were performed for base and sub-base temperature data (Fig. 7) to study the highest internal similarity among the temperature behaviour within different types of pervious pavements, forming groups that are scarcely similar to the other groups. Clustering results of the sub-base temperatures, using the average linkage agglomerative method, showed the formation of two groups of high similarities, which correspond to the reinforced grass and concrete block type. This grouping has the most intergroup differences compared to another composed of porous concrete and porous asphalt types.

Relating to the base temperatures, the same two groups are strongly differentiated. On the other hand, the most important similarities correspond to the reinforced grass with concrete grid and concrete block with geotextile pervious pavement types. The presence of a single group of concrete block and reinforced grass type respectively, obtained in the clustering analysis, indicates that the temperature of the sub-base may be not affected by the presence or absence of the geotextile layer.

Monthly mean temperatures of the pervious pavements at 0.15m and 0.50m depth are normally distributed. Sub-base monthly mean temperatures are higher than air monthly mean temperatures during the entire period for the pervious pavement typologies of porous asphalt and porous concrete; though reinforced grass and concrete block sub-base temperatures are slightly lower than air temperatures during the autumn and winter months (Fig. 8).

If the pervious pavement typologies are considered as three categories: continuous surface (PA and PC), open surface (CB) and reinforced grass surface (RG), a monthly analysis found the temperature response of these types to be significantly different (ANOVA, $p < 0.05$) during the period of study. The variance analysis shows significant differences among the monthly mean temperatures for the types of pervious pavements obtained in local weather conditions; according to the Tukey Honestly Significant Difference test, which revealed two groups significantly different: one composed of open surface and reinforced grass type and another for the continuous surface type; according to the differences showed in the dendograms for the base and sub-base temperatures.

In order to study the influence of the geotextile in the temperature response within the pervious pavement due to the results observed in the dendograms, a T-test is performed for the sub-base monthly mean temperatures obtained. The differences between the presence and absence of geotextile in the pervious pavement sub-base monthly mean temperatures were not found significant ($p > 0.05$).

Finally, a non-parametric test is performed to describe the relationship between the temperature behaviour of different pervious pavements and the climatic variables. Correlation analyses among the temperatures registered within the sub-base of different types of pervious

pavements are summarized by Spearman's rank correlation coefficients in Table 2. Results of the statistical analysis indicate that the sub-base temperatures are highly correlated with air temperature and less correlated with solar radiation, while precipitation and wind speed are inversely correlated. Precipitation and wind speed are involved in the cooling processes occurred in the surface but rain events after sunny days could transfer the heat stored in the pavement to the sub-base and the correlation with the sub-base temperatures is not as high as for the wind speed. From the correlation indexes, slight differences can be appreciated: reinforced grass type presents the smallest correlation with precipitation and this could be due to the construction of these surfaces made of 100% of natural soil, instead of the experimental design of the grass reinforced surfaces which included 50% of natural soil and 50% of sand. This made these pavements more compact and impervious, so less rainwater could infiltrate. Continuous surface type (PA and PC) presents the smallest correlation with air temperature and solar radiation. This may have happened because these porous surfaces could retain more water which is available for being evaporated and the heating process may be delayed.

3.2. Water quality

Maximum sub-base temperatures during the hottest season obtained in the parking area since the period of study began have been higher than 29°C, so that *Legionella* could reproduce in this media if it were present.

The physicochemical analyses results of the water samples are summarised in Table 3. Some parameters of water quality show great variability as three replicates of each pervious pavement type were collected from different parking bays of the same type and construction characteristics, instead of taking samples from the same sub-base. Iron concentrations were not determined because prior analyses resulted in concentrations below the detection limit. The concentration ranges of OQD, total phosphorus, total nitrogen and turbidity were relatively low for urban runoff, regarding the nutrient and sediment removal of the pervious pavements. The mean pH values obtained can be described as slightly alkaline for all the pervious pavement

typologies. The conductivity and total hardness values obtained are due to the presence of limestone aggregate in the sub-base.

Legionella detection was carried out according to the ISO 11731:1998 standard procedures and non positive results were obtained in the samples analyzed, so there was no presence of Legionella in the sub-bases of the pervious pavements selected under the analysis method employed in this study. Therefore, the aquatic environment created in the sub-base does not represent a source of Legionella under the specific conditions experienced and after one year of operation of the pervious pavements parking lot, but more water analyses are necessary for a definitive confirmation.

4. Conclusions

The results obtained provide an extensive overview of the temperature performance within different pervious pavements in order to evaluate the possibility of using them as a GSHP system, in addition to their use as an instrument for rainwater management and urban heat island reduction.

The sub-base temperatures maintain lower daily temperature oscillations than base temperatures because the sub-bases are buffered from daily changes even when there is still some influence of the ambient temperature. Sub-base temperatures can be associated with the insulating ability provided by these types of pervious pavements, so the heat storage capacity of the water and aggregate, and the pervious pavement enable the sub-base to be used to maintain the water temperature significantly different from the air temperature.

Two groups were differentiated regarding temperature behaviour within pervious pavements: open surfaces and reinforced grass surfaces (CB and RG); and continuous surfaces (PA and PC). The temperature differences were demonstrated to be statistically significant for the monthly analysis for the base and sub-base temperatures in these two groups. The heat gain from the pervious pavements is more pronounced in the continuous surface type during the summer months. On the other hand, the influence of the geotextile on the temperature response of the pervious pavements was not demonstrated to be statistically significant.

Sub-base temperatures of these pavements are higher than air temperatures during the summer months, when the cooling mode design of the GSHP system is intended to be used. Consequently the investigation site does not seem appropriate to be used as a heat sink. However, in the heating mode design, the sub-base would be used as a heat source, so temperatures higher than ambient temperature are desirable and have been achieved in a discontinuous form during the autumn and winter months due to the mild weather for the area.

If the thermal environment of the sub-bases is altered for energy applications, the rainwater reservoir does not represent a health risk associated with occurrence of *Legionellae*, but periodic water quality control is recommended if the sub-base temperatures may be disturbed.

REFERENCES

- Asaeda T, Ca VT (2000) Characteristics of permeable pavement during hot summer weather and impact on thermal environment. *Building and Environment* 35:363-375
- Bäckström M (2000) Ground temperature in porous pavement during freezing and thawing. *Journal of Transportation Engineering* 126(5):375-381
- Brattebo BO, Booth DB (2003) Long-term stormwater quantity and quality performance of permeable pavement systems. *Water Research* 37:4369-4376
- Coupe SJ, Charlesworth S, Faraj AS (2009) Combining permeable paving with renewable energy devices: installation, performance and future prospects. 9th International Conference on Concrete Block Paving. Buenos Aires, Argentina, 2009
- Day GE, Smith DR, Bowers J (1981) Runoff and pollution abatement characteristics of concrete grid pavements. Bulletin 135, Virginia Water Resources Research Center, Virginia State University. USA
- Field R, Masters H, Singer M (1982) Status of porous pavement research. *Water Research* 16(6):849-858
- Fields BS (1996) The molecular ecology of legionellae. *Trends in Microbiology* 4(7):286-290

- Fields BS, Benson RF, Besser RE (2002) Legionella and Legionnaires' Disease: 25 Years of Investigation. *Clinical Microbiology Reviews* 15(3):506–526
- Gilbert JC, Clausen JC (2006) Stormwater runoff quality from asphalt paver, and Crushed Stone Driveways in Connecticut. *Water Research* 40:826-832
- Gomez-Ullate E, Castillo-Lopez E, Castro-Fresno D, Bayon JR (2010) Analysis and contrast of different pervious pavements for management of storm-water in a parking area in Northern Spain. *Water Resource Management* 25 (6): 1525-1535
- Kaini, P., Artita, K., & Nicklow, J. W. (2012). Optimizing structural best management practices using SWAT and genetic algorithm to improve water quality goals. *Water Resources Management*, 26(7): 1827-1845.
- Kevern JT, Schaefer VR, Wang K (2009) Temperature behaviour of pervious concrete system. *Transportation Research Record: Journal of Transportation Research Board* 2098:94-101
- Legret M, Colandini V (1999) Effects of a porous pavement with reservoir structure on runoff water: water quality and fate of heavy metals. *Water Science and Technology* 39(2):111-117
- Newman AP, Pratt CJ, Coupe S, Cresswell, N (2002) Oil biodegradation within permeable pavements by microbial communities. *Water Science and Technology* 45(7):51-56
- Panagopoulos, Y., Makropoulos, C., & Mimikou, M. (2011). Diffuse surface water pollution: Driving factors for different geoclimatic regions. *Water Resources Management*, 25(14): 3635-3660.
- Pratt CJ, Mantle JD, Schofield, PA (1989) Urban stormwater reduction and quality improvement through the use of permeable pavements. *Water Science and Technology* 21(8-9 pt 3):769-778
- Pratt CJ, Mantle JD, Schofield, PA (1995) UK research into the performance of permeable pavement, reservoir structures in controlling stormwater discharge quantity and quality. *Water Science and Technology* 32(1):63-69
- Pratt CJ (1999) Use of permeable, reservoir pavement constructions for stormwater treatment

- and storage for re-use. *Water Science and Technology* 39(5):145-151
- Raimbault G, Balades J-D, Faure-Soulet A (1985) Quatre expérimentations françaises de chaussées poreuses. *Bulletin de liaison des laboratoires des ponts et chaussees* 137:43-55
- Rodriguez J, Castro D, Calzada MA, Davies JW (2005) Pervious pavement research in Spain: structural and hydraulic issues. *Tenth International Conference on Urban Drainage, Copenhagen/Denmark*, pp. 21-26
- Sanner B, Karytsas C, Mendrinou D, Rybach L (2003) Current status of ground source heat pumps and underground thermal energy storage in Europe. *Geothermics* 32(4): 579-588
- Scholz M, Grabowiecki P (2007) Review of permeable pavement systems. *Building and Environment* 42:3830-3836
- Scholz M, Grabowiecki P (2009) Combined permeable pavement and ground source heat pump systems to treat urban runoff. *Journal of Chemical Technology and Biotechnology* 84:405-413
- Tota-Maharaj K, Scholz M, Ahmed T, French C, Pagaling E (2010) The synergy of permeable pavements and geothermal heat pumps for stormwater treatment and reuse. *Environmental Technology* 31(14):1517-1531
- Vu Thanh CA, Takashi A (1997) Evaporation at the surface of permeable pavement and its impacts on the urban thermal environment. *Proceedings, Congress of the International Association of Hydraulic Research, (IAHR)*. Vol A: 104-109
- Wanphen S, Nagano K (2009) Experimental study of the performance of porous materials to moderate the roof surface temperature by its evaporative cooling effect. *Building and Environment* 44: 338-351

LIST OF FIGURES

Fig. 1 Pervious pavement types under study: (a) reinforced grass; (b) porous concrete; (c) porous asphalt; and (d) concrete block

Fig. 2 Location of the pervious pavement bays selected in the experimental parking area

Fig. 3 Cross section of a pervious pavement parking bay

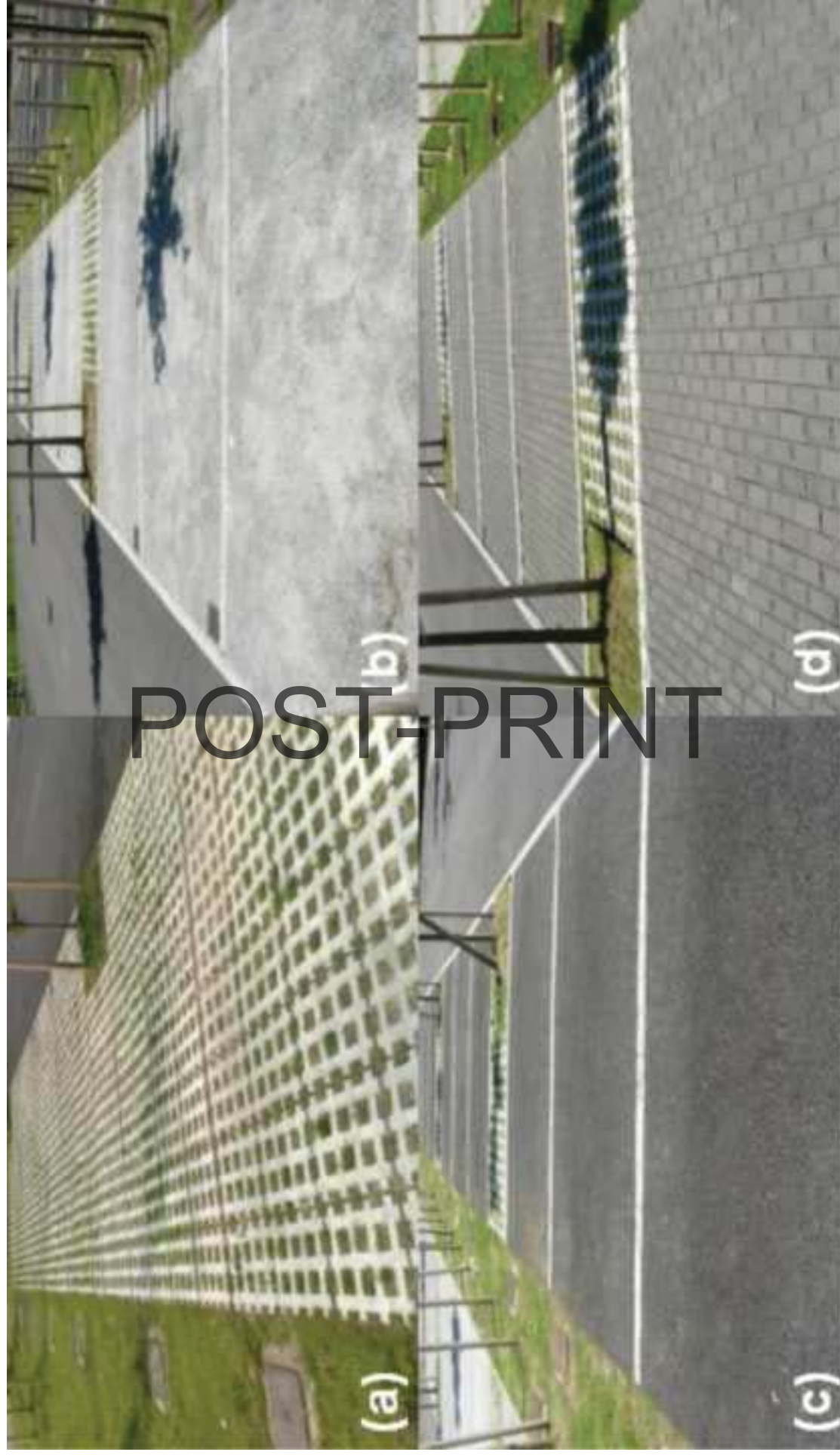
Fig. 4 Temperature and precipitation during 9 to 18 Feb 2009

Fig. 5 Temperature and precipitation during 1 to 15 Aug 2009

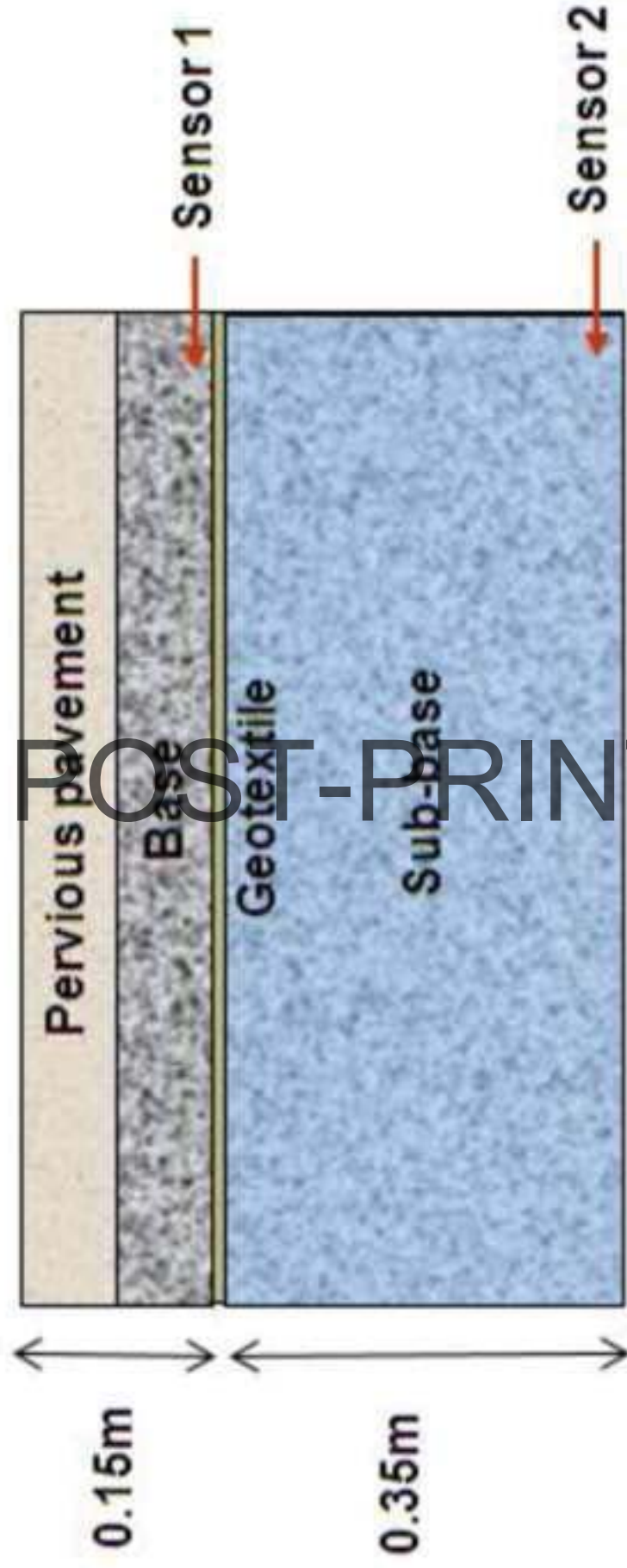
Fig. 6 Temperature and precipitation during 1 to 15 Nov 2009

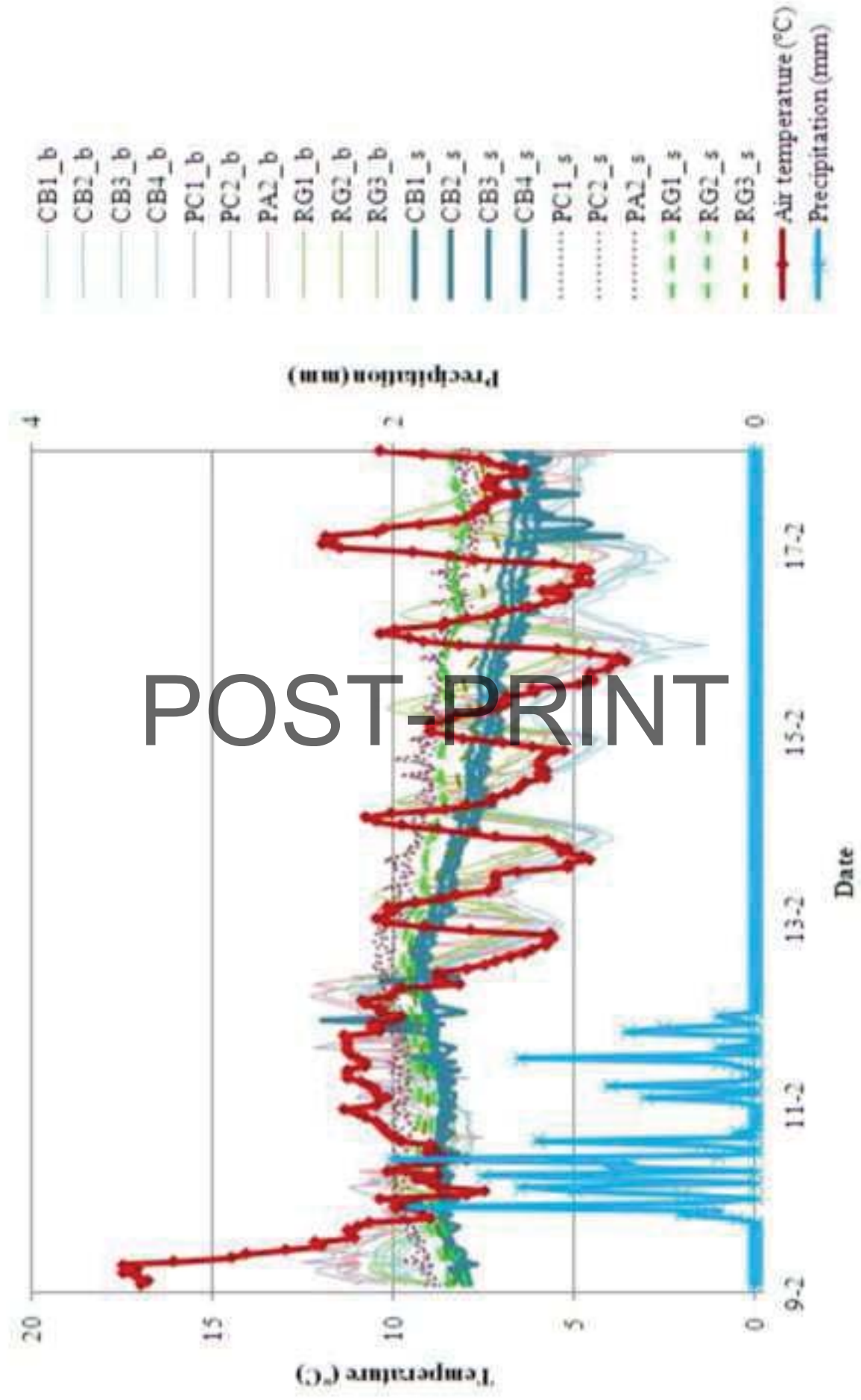
Fig. 7 Dendrogram showing clusters: (a) base temperatures; and (b) sub-base temperatures

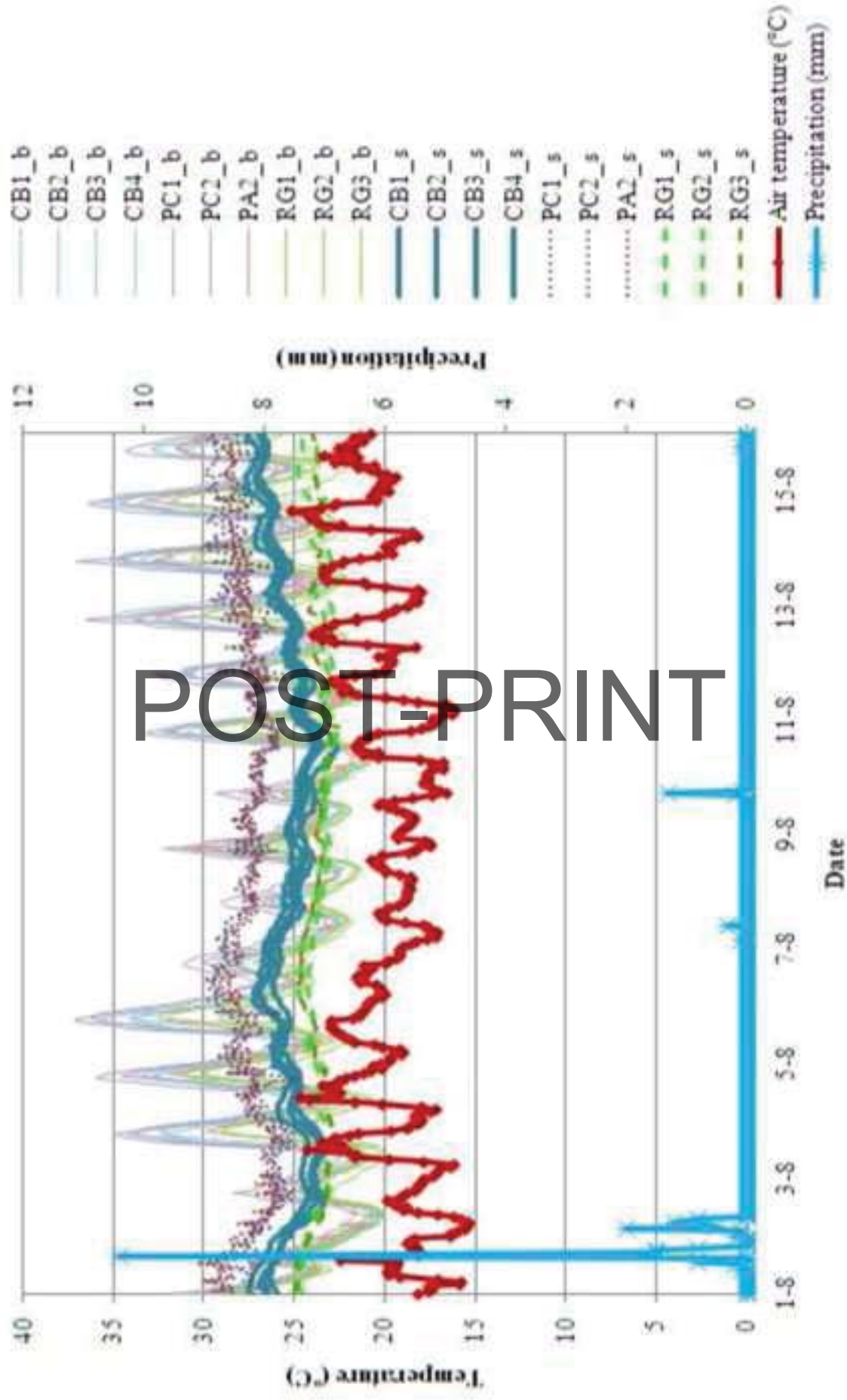
Fig. 8 Monthly sub-base mean temperatures measured during the period of study

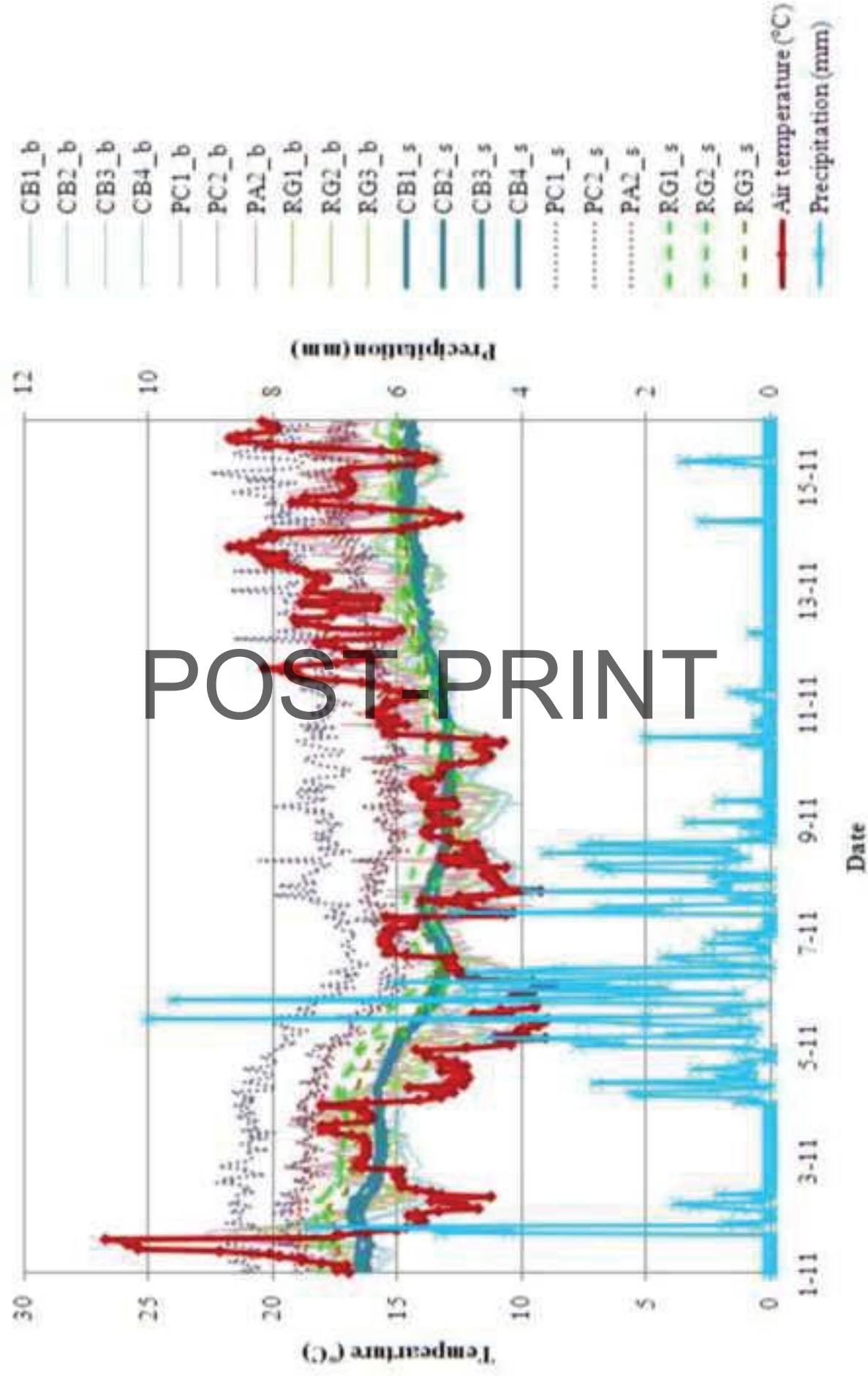


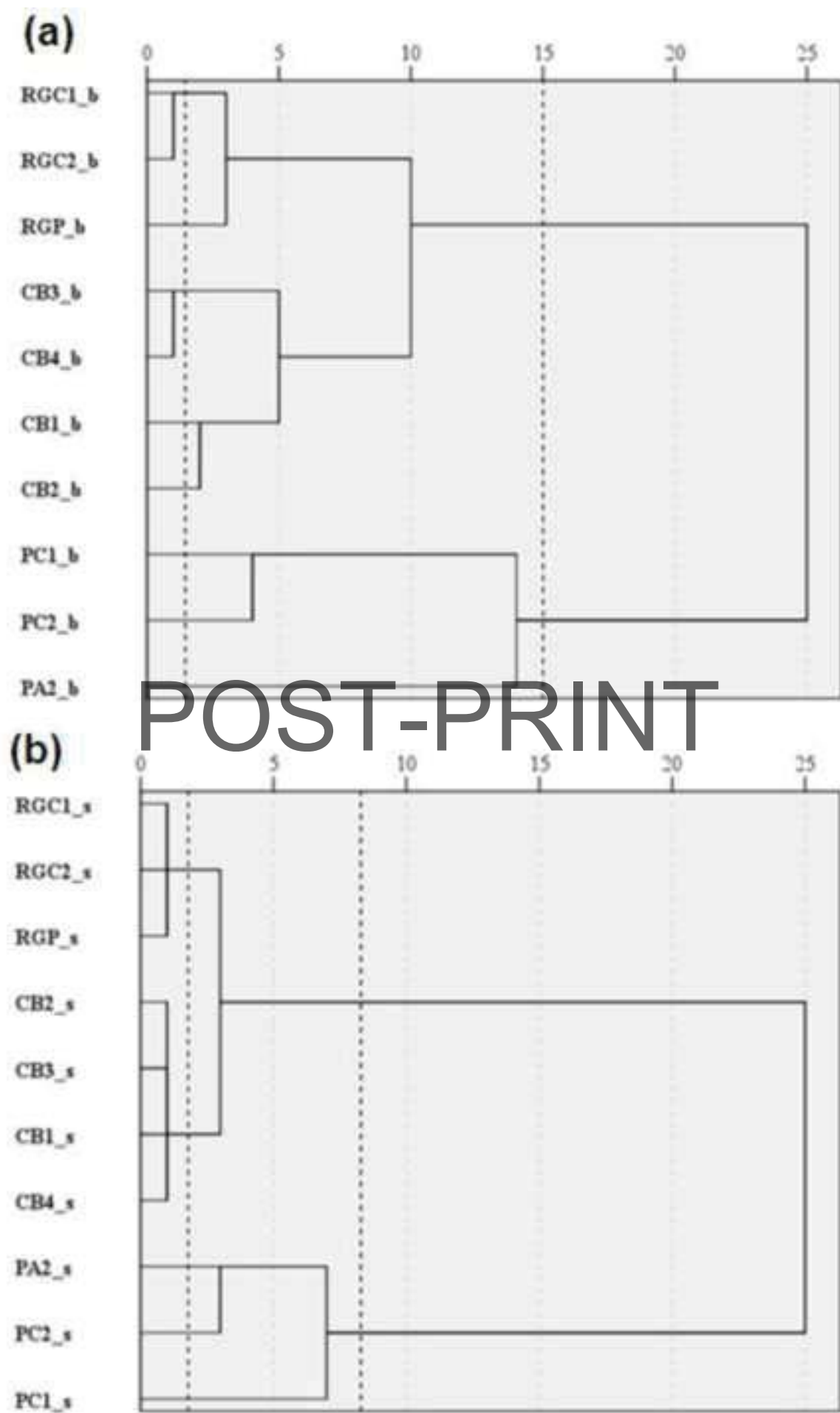


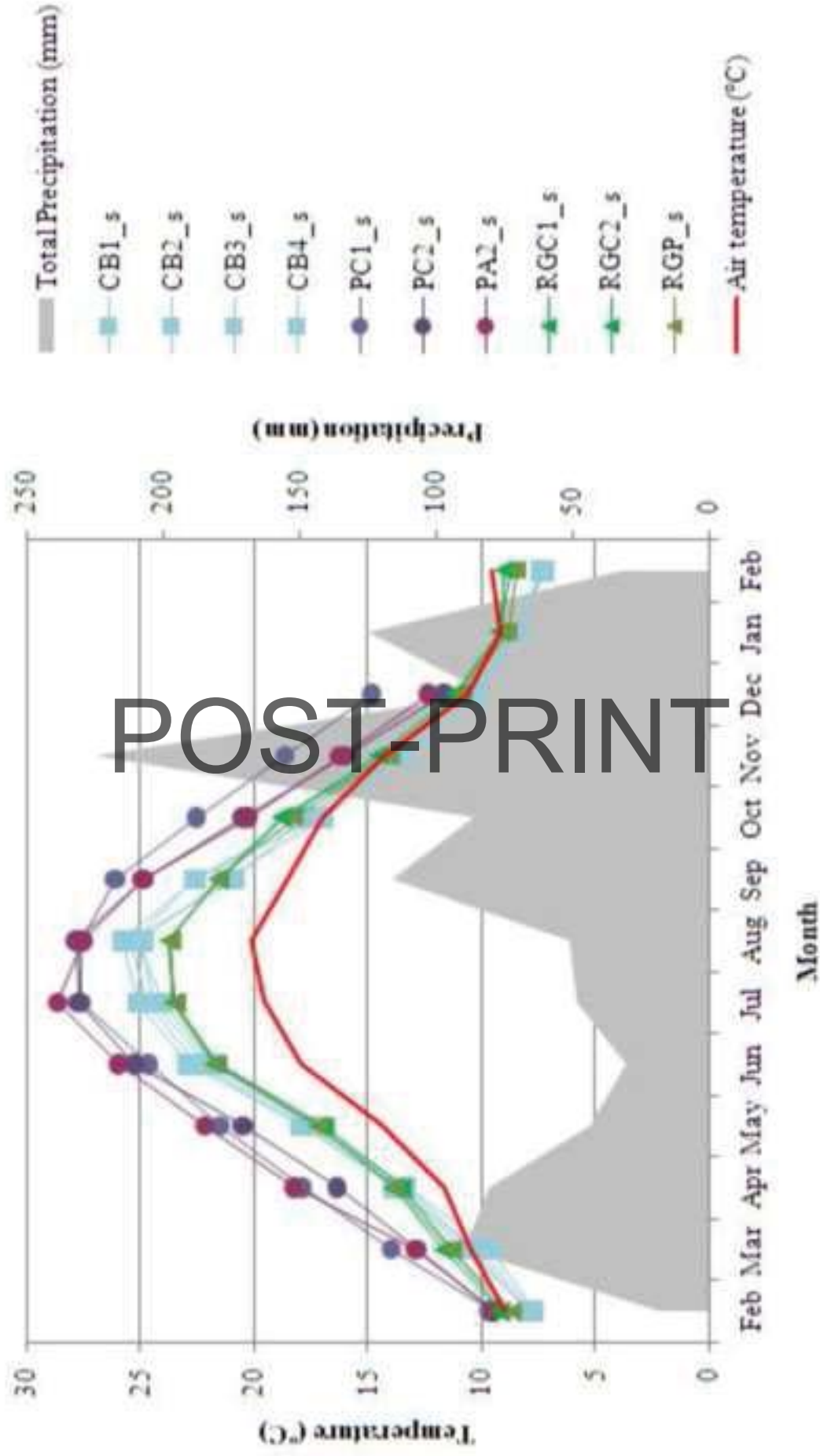












PARKING BAY	SURFACE	BASE	GEOTEXTILE	SUBBASE
CB1	Concrete block	Limestone gravel (2-6 mm)	Without geotextile	Limestone aggregate (4-20 mm and 10-63 mm)
CB2	Concrete block	Limestone gravel (4-8 mm)	Without geotextile	Limestone aggregate (4-20 mm)
CB3	Concrete block	Limestone gravel (4-8 mm)	Non woven polyester 150 gr/m ²	Limestone aggregate (4-20 mm)
CB4	Concrete block	Limestone gravel (4-8 mm)	Non woven polyester 150 gr/m ²	Limestone aggregate (4-20 mm)
PA1	Porous asphalt PA12	Limestone gravel (4-20 mm)	Non woven polyester 150 gr/m ²	Limestone aggregate (4-20 mm)
PA2	Porous asphalt PA12	Limestone gravel (4-20 mm)	Without geotextile	Limestone aggregate (4-20 mm)
PC1	Porous concrete	Limestone gravel (4-20 mm)	Non woven polyester 150 gr/m ²	Limestone aggregate (4-20 mm)
PC2	Porous concrete	Limestone gravel (4-20 mm)	Without geotextile	Limestone aggregate (4-20 mm)
RGC1	Reinforced grass with concrete grid	Limestone gravel (4-8 mm)	Non woven polypropylene 155 gr/m ²	Limestone aggregate (4-20 mm)
RGC2	Reinforced grass with concrete grid	Limestone gravel (4-8 mm)	Without geotextile	Limestone aggregate (4-20 mm)
RGP	Reinforced grass with plastic grid	Limestone gravel (4-8 mm)	Non woven polypropylene 155 gr/m ²	Limestone aggregate (4-20 mm)

Table 1 Pervious pavements bays characteristics and construction materials employed

Parking bays	Spearman's rho	Air temperature (°C)	Precipitation (mm)	Solar radiation (KJ/m²)	Wind speed (Km/h)	Relative humidity (%)
CB1_s	Correlation Coefficient	0.839**	-0.100**	0.173**	-0.279**	0.227**
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	8484	8484	8484	8454	8484
CB2_s	Correlation Coefficient	0.833**	-0.102**	0.166**	-0.280**	0.234**
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	8484	8484	8484	8454	8484
CB3_s	Correlation Coefficient	0.829**	-0.104**	0.180**	-0.279**	0.237**
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	7645	7645	7645	7615	7645
CB4_s	Correlation Coefficient	0.838**	-0.099**	0.161**	-0.275**	0.236**
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	8484	8484	8484	8454	8484
PC1_s	Correlation Coefficient	0.804**	-0.106**	0.127**	-0.265**	0.156**
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	7428	7428	7428	7398	7428
PA2_s	Correlation Coefficient	0.774**	-0.105**	0.154**	-0.272**	0.169**
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	7374	7374	7374	7344	7374
PC2_s	Correlation Coefficient	0.799**	-0.110**	0.138**	-0.276**	0.185**
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	7428	7428	7428	7398	7428
RGC1_s	Correlation Coefficient	0.840**	-0.077**	0.165**	-0.274**	0.250**
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	8861	8838	8861	8831	8861
RGC2_s	Correlation Coefficient	0.836**	-0.070**	0.172**	-0.268**	0.250**
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	8861	8838	8861	8831	8861
RGP_s	Correlation Coefficient	0.838**	-0.074**	0.164**	-0.272**	0.260**
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	8861	8838	8861	8831	8861

**, Correlation is significant at the 0.01 level (2-tailed).

Table 2 Correlation between the different pervious pavement sub-base temperatures and the climatic variables

Parking bay types	Concrete block	Porous asphalt	Reinforced grass with concrete grid
PARAMETERS	Mean ^a (N=3)	Mean ^a (N=3)	Mean ^a (N=3)
Turbidity (NTU)	8.133 (1.966-14.300)	42.000 (-70.525-154.525)	16.167 (-10.929-43.262)
Conductivity (µS)	427.333 (273.149-581.516)	310 (281.351-338.648)	427.333 (367.696-486.969)
Temperature (°C)	22.067 (21.549-22.583)	22.233 (21.292-23.173)	21.033 (20.889-21.176)
Dissolved oxygen (mg/l)	4.223 (1.663-6.783)	3.667 (3.302-4.030)	2.523 (0.963-4.082)
Ph	7.713 (7.163-8.263)	7.873 (7.797-7.949)	7.62 (7.168-8.071)
Total hardness (mg/l)	136.467 (85.408-187.524)	136.467 (110.937-161.995)	166.133 (140.604-191.662)
OQD (mg/l)	5.323 (1.054-9.591)	10.527 (8.845-12.208)	6.56 (3.311-9.808)
Total phosphorus (mg/l)	0.019 (-0.013-0.051)	0.023 (0.004-0.041)	0.026 (0.019-0.031)
Total nitrogen (mg/l)	0.738 (-0.332-1.808)	0.5 (0.097-0.901)	0.38 (0.165-0.594)
Heterotrophic bacteria 22 °C (CFU/ml)	5.567E+07 (1.41E+07-9.73E+07)	1.968E+09 (-2.51E+09-6.44E+09)	1.415E+09 (-1.53E+09-4.36E+09)
Heterotrophic bacteria 36 °C (CFU/ml)	4.153E+08 (-1.17E+09-2.00E+09)	2.317E+07 (-8.85E+06-5.52E+07)	3.150E+07 (-1.30E+07-7.60E+07)

^a95 % confidence interval

Table 3 Mean concentrations of subbase water analysis for the pervious pavement parking bays selected